National Institute of Standards and Technology
U.S. Department of Commerce

MML Measures Up
MATERIAL MEASUREMENT LABORATORY

Measuring Durability

Edward Garboczi
National Institute of Standards and Technology
Applied Chemicals and Materials Division
Boulder, Colorado USA

Vision of concrete materials

- At any geographical location, in any climate, with any local materials

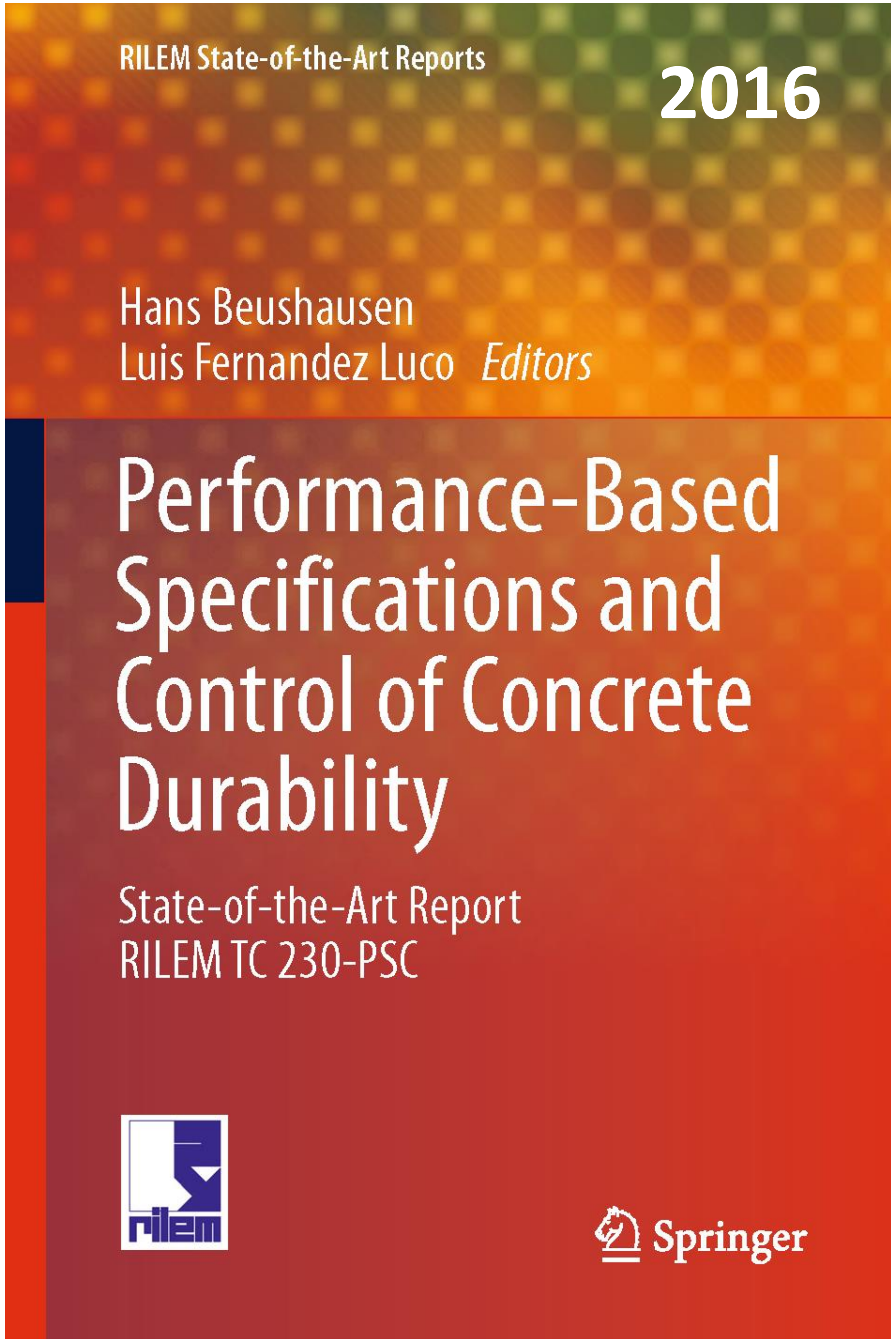
- Make concrete that has the performance required for the specified job
  - “Performance” includes any mechanical, chemical, permeability, durability, and service life required for the desired use

Extremely Durable Concretes and Cementitious Materials

- 16 projects in program
- 10 are for new materials intended to be more durable
- 1 is on measurement of thermodynamic and kinetic parameters related to curing and long-term durability
- My talk is directed towards these 11

How do we measure concrete durability?

- Not a direct measurement like diffusivity, electrical resistivity, or compressive strength
- Prediction, based on measured parameters and some knowledge of various threshold limits
  - The uncertainty in a prediction certainly far exceeds any uncertainty in measured parameters
- Put simply: we cannot routinely measure whether a new concrete material has increased durability
  - One reason – concrete is a complex random porous composite
  - Second reason – expected service life is on the order of decades, far beyond what we expect of most materials exposed to the environment
- And for a new material, we need to ask:
  - Do standard tests and prediction techniques apply?
  - “New material” includes regular concrete with waste materials dumped into it



RILEM TC 230-PSC was focused on corrosion of reinforcement via intrusion through cover concrete

No apparent US members, finished in 2016

“Performance-based” means choosing and measuring parameters that will affect service life

“Prescriptive-based” means specifying the exact materials thought to be needed to achieve the desired service life

Durability: corrosion of reinforcing steel

- Measure all the possible rates for chloride ions to penetrate concrete cover
    - Diffusivity, capillary suction
- Measure/predict all the ways that these rates could change over time
    - Cracking susceptibility, environment

- Service life or durability prediction based on how long it will take to get the chloride at the steel to be at the level needed to initiate corrosion
- Change chloride level needed for corrosion
    - Type of steel used – increase chloride threshold needed to initiate corrosion
    - Polymer composite reinforcing rods – remove corrosion as a failure mechanism

Durability due to chemical deterioration

- We don’t directly measure rates of chemical deterioration
- Only try to ensure that chosen materials don’t degrade in certain ways
  - Assuring aggregate will not undergo appreciable alkali-silica reaction
  - Assuring cement will not undergo appreciable sulfate attack
- ASTM standard measurement is to make a mortar bar and put it in bucket with higher amounts of the chemical of interest and wait six months (or longer) for mechanical deterioration
  - And shorter tests always need to be confirmed with longer tests
- Note: new material could pass this test by not having this kind of reactivity
- These tests are empirical

What are we missing?

- Is there any way to directly measure “durability?” Others might think of how to do this - I can’t
- “Durability” is a complex phenomenon that cannot be simply experimentally measured, since concrete is a complex material

- Two ways of making progress
- Accelerated measurements
- Accurate/fast/basic models, which need material characterization and fundamental thermokinetic data

Accelerated durability tests

- Standard approach for many materials, e.g. polymer films and UV irradiation, metal fatigue tests
- Must be careful to: (1) accelerate without changing the mechanism, and (2) have a validated superposition principle like time-temperature for polymers
- Might be able to do some acceleration of this type for concrete without changing mechanisms but only a modest amount
- Not nearly enough for measuring/predicting service lives of 100 years

“Accelerated” measurements

- Some “acceleration” in concrete measurements can be done using materials science
- To measure ASR susceptibility of aggregates, why make a mortar bar and slow down the measurement with ions slowly diffusing through the cement paste matrix?
- Test aggregates directly – limited amount of work down on this but should be feasible – needs some basic research on ASR mechanisms and careful characterization of aggregate mineralogy
  - Some work has been done on this: Dan Zollinger, Texas A&M

"Accelerated" measurements

- When measuring the effect of sulfate attack on cement, the mortar bar confounds the measurement with slow sulfate ion diffusivity/reactivity through the large-ish (3 cm x 3 cm x 25 cm) bar
- Why not make very small bars of cement paste and test those directly?
  - Work of Chiara Ferraris, NIST

“Accelerated” measurements

- There are probably other ways to do this kind of materials-science-based acceleration
- Note – these are not really “accelerated” tests, where a superposition principle can be used to extend the results out to N years
- Rather, they are much faster and more accurate ways of measuring durability parameters, still empirical but much faster
- Still have the problem of predicting durability, but may have reduced testing time from months to weeks or days
  - The durability prediction part is usually much faster than measuring parameters

Use of models

- The whole point of NIST modeling work 1989-2017 was to develop accurate multi-scale microstructural models that could be used to perform accelerated, accurate aging
- Developing the multi-scale microstructural models was hard and data was missing
- Some pieces are still in use around the world
    - CEMHYD3D, HydratiCA, Anm, VCCTL
- Current models are not good enough and lack data for accurate aging/durability prediction
- This is still a viable route but will need a substantial new, long-term (~10 years, 5-10 people) investment to develop these models - if needed data can be generated…

Data: Dissolution, Reaction and Growth

- Mechanistic knowledge for mineral dissolution, reactions, diffusion, and growth
  - For single materials and for complex mixtures
- Mechanistic knowledge of how chemical admixtures work
- The nice thing about this data is that it is "once and done" since these are fundamental parameters

Data: Characterization of materials

- Need to identify what needs to be characterized – implies detailed knowledge of chemistry and reactions/kinetics
  - e.g., I am sure that judging fly ash to be Class C vs. Class F is not detailed enough
- Need standard, validated, fast methods to measure quantities that models can actually use
  - e.g., slump test vs. rheology measurements calibrated by NIST SRMs
- Need to characterize aggregate mineralogy
- The only way to do this is through better knowledge of fundamental chemistry and physics

Thermokinetic Database

- When a new material is encountered, and proves useful, once it is characterized it would go into a national/international thermokinetic data base
- NIST can host such a database – we already do many others
- Or perhaps just build on growing databases at EMPA and Paul Scherrer Institute in Switzerland

Summary of key points

- Vision of concrete materials work: at any geographical location, in any climate, with any local materials, make concrete that has the performance required for the specified job
- Durability is not a direct measurement but is better described as a prediction
- We cannot simply and routinely measure whether a new concrete material has increased durability
- Two ways of making progress: accelerated measurements and accurate/fast/basic models combined with material characterization and fundamental thermokinetic data

The scientist does not aim at an immediate result and does not expect that his/her advanced ideas will be readily taken up. His/her work is like that of the planter -- for the future, whose duty is to lay the foundation for those who are to come and point the way.

- Nikola Tesla, physicist, engineer, and inventor (slightly edited)